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A Framework For Investigating The Application Of Educational Theories In Engineering Education Research

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A FRAMEWORK FOR INVESTIGATING EDUCATIONAL THEORIES IN ENGINEERING EDUCATION RESEARCH

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ABSTRACT

Grounding the design of educational interventions and their analysis in theory allows us to understand and interpret results of interventions and advance educational theories. Moreover, building an understanding of *which* educational theories are used and *how* they are used can build a consensus among researchers and mature the research

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in a field. In this paper, we investigate the extent to which educational theories are used to ground the design, analysis, and evaluation of learning activities in engineering education. For this purpose, we developed a coding instrument to determine: (1) which educational theories are expressed in studies investigating learning activities and interventions, and (2) the extent to which these theories inform (a) the design of an intervention and (b) the analysis of that intervention. The instrument was applied to a sample of 12 studies from an existing literature review on collaborative engineering design activities to demonstrate the relevance of the developed framework. Results reveal that most studies refer to educational theory, primarily pedagogical approaches such as project-based learning. Furthermore, half of the time, the design of learning interventions is grounded in theory, however, the evaluation of those interventions is often not connected to educational theories.

1 INTRODUCTION

Engineering Education Research (EER) is a relatively new research field that has grown significantly over the past decades (Borrego and Bernhard 2011). EER originates from the engineering field and was particularly shaped by scholars with an interest in education. As a young and interdisciplinary field, EER faces several challenges. The field's interdisciplinary nature leads to widely varying methodological approaches and reporting practices, making it difficult to accumulate findings and assess the effectiveness of educational approaches (Borrego 2007; Power 2021). Furthermore, it results in a multitude of theories which makes generalizing and reaching conclusions difficult. As a result, EER is characterized as a field with “low consensus” (Borrego 2007; Power 2021). This is challenging for engineering educators, who naturally come from a field with a high consensus (Power 2021).

To help engineering educators and advance EER, we suggest the discipline focuses on understanding the use of educational theories in EER. Since methodological choices cannot be separated from theoretical perspectives (Case and Light 2011), we specifically aim to investigate how educational theories are integrated into EER. We are interested in (1) which educational theories are expressed and reported on, and (2) the extent to which these theories inform (a) the design of an intervention and (b) the analysis of that intervention. Hence, we designed a framework to systematically analyze any body of literature within EER and related fields. Such systematic literature reviews are an essential step to a more mature research field and more consensus (Borrego et al 2014; 2015; Power 2021). Conducting literature reviews with this framework thus helps in generating conclusions on to what extent educational theories are grounded in the design, the analysis, and the evaluation of learning activities.

In this paper, we will present the framework, demonstrate how it can be used, and show that our framework is able to measure and monitor to what extent results are used to advance the existing theories. As a case study, we focus on educational theories expressed in research on collaborative engineering design education and present some of the results that were obtained during the validation and use of the instrument. Although the framework is universally applicable to the literature on educational interventions, we selected this topic as a case study as design is a core activity in the engineering domain (Dym et al. 2005). With our work, we hope to contribute to the advancement of the EER discipline.

2 WHY THIS STUDY?

Research into the use of theories in EER fields is not new. Earlier work looked into this topic from different perspectives and disciplines. Most of this literature provides insight into whether educational theories were used and which ones occurred most frequently.

An analysis of publications from the Journal of Engineering Education (JEE) between 1993-2002 revealed that less than 20% of papers used an educational theory to design or analyze curriculum, learning, or teaching (Wankat 2004). In contrast, Borrego et al. (2013) found that educational theories were mentioned regularly in team-based engineering projects, with literature on problem-based learning, globally distributed teams, active learning, learning styles, and Kolb's experiential learning cycle being the most popular. More recently, Malmi et al. (2018) analyzed 155 papers published in the European Journal of Engineering Education (EJEE) in 2009, 2010, and 2013, with the aim of investigating research processes in EER. This includes links to relevant theories and explanatory frameworks. In line with Borrego et al. (2013), they found that 72% of the papers applied some form of "explanatory framework" and, thus, they argue that the use of educational theories in the field is increasing. In total, the authors counted 128 different explanatory frameworks, which not only indicates a richness of theories but also captures a variety of theories that might be outside the scope of many researchers. Some of the most frequently mentioned frameworks include theories of learning, such as (social) constructivism, and models underlying specific types of science/engineering curricula, such as problem-based learning. It was concluded that even though most papers apply some explanatory framework, the chosen frameworks are often very specific and not connected to those frameworks that are most well-known or most firmly established, which they attribute to the young age of the EER discipline (Malmi et al. 2018).

The above-mentioned works (Malmi et al. 2018; Borrego et al. 2013; Wankat 2004) made considerable efforts to identify what (educational) theories are used in the EER discipline. Nevertheless, they do not specify how they consistently measured theories in terms of how theories are used for designing and analyzing learning activities, nor to what extent theories are used. It is therefore unknown how many papers "just mentioned" educational theories. Moreover, what is considered an educational theory differs per work or is unspecified. Similar issues are found in related, equally young disciplines such as Computing Education Research (CER). For this discipline, Malmi et al. (2014) found that 80% of CER literature (2015-2011) did not build on theoretical research from education, and nearly half of the research did not build on any theory at all, irrespective of the original discipline. Important to note is that a "loose" definition of theory was adopted, and numbers are small. The analysis did not address how theories are used specifically.

Recent efforts to investigate specific uses of learning theories in CER also looked into co-occurrences of the mentioned theories. In Szabo et al. (2019) three “communities of learning theories” were distinguished, namely, social theories, experiential theories, and theories of mind. This was further developed by Szabo and Sheard (2022), who distinguished six communities: behaviorist and cognitivist learning theories, working memory theories, social cognition theories, motivation learning theories, behaviorist and cognitivist meta-theories, and specific computing education learning theories. For the specific computing education learning theories, Szabo and Sheard (2022) further analyzed the quality of the theory connections by applying their Taxonomy of Learning Theory Connections, which investigates the extent to which theories are mentioned together. Their developed scale distinguishes between learning theories that are causally referenced, separately discussed, together discussed, critically compared, part of the analysis or design of the intervention/design of artefacts, and theory development. Although no such analysis was provided for the other communities of theories, this was the first framework we encountered to investigate deeply how educational theories are used in a discipline.

As is clear from the previous section, most frameworks focus on what educational theories are used but do not look at how the theories are used and advanced. In our framework, we distinguish between the design of a learning activity and the analysis of data. Moreover, we created a validated framework that can be applied to different disciplines and thus can be universally used. Our preliminary validation study also gives an indication of how the framework can be further used to provide insights into the embedding of educational theories in EER and related disciplines.

3 METHODOLOGY

3.1 Study design

To develop a framework to assess how articles concerning learning activities are grounded in educational theories, we used a body of literature from an existing systematic review (van Helden et al. 2023) on the implementation of collaboration in engineering design education to test and validate the framework. This systematic review followed Preferred Reporting Items for Systematic review and Meta-Analyses protocols (PRISMA) (Page et al. 2021) to select 111 studies. From these 111, we randomly selected 2x3 studies to develop and test our framework and another 12 studies for testing and the first results.

3.2 Development of the framework

The first three authors co-designed the framework in three iterations, of which an overview is presented below. The final framework and scales are presented in the next section, Table 1, and Figure 1. During the first iteration, the first author proposed an initial version of the framework based on our main research questions. Following this framework, a coder first identifies all educational theories mentioned in a paper. Next, using three scales with predefined items, the coder rates the extent to which this educational theory was embedded in (1) the background (i.e., introduction, related work), (2) the design of the intervention (i.e., methods), and (3) the analysis of the intervention (i.e., results, discussion, conclusion). The originally proposed scales were refined through discussion and incorporating suggestions from the second and third authors.

Next, the first three authors used the framework to code three randomly selected papers (Teiniker, Paar, and Lind 2011; Demara et al. 2017; Du et al. 2020). We compared our results of the coding of this first iteration, discussed disagreements, and resolved misalignments. For example, in the scale 'embedding in background', we initially distinguished between articles that give only a definition of a theory and articles that also provide further explanation or examples. However, the boundary between 'definition' and 'additional explanation and example' was not as clear as anticipated beforehand, hence we merged these items. We also created a binary scale for mentions of educational theories in the abstract (including title and keywords). After solving all disagreements in a similar way, three new randomly selected papers (Ardaiz-Villanueva et al. 2011; Alorda, Suenaga, and Pons 2011; Baumann 2020) were coded by the same three authors, using the new iteration of the framework.

When comparing the results of the second iteration, we found some misalignment between coders in what should be considered an educational theory. To avoid this in the future, a list was created with the most commonly mentioned educational theories in EER, taking into account prior studies. To maintain a clear and structured process, when a coder encountered a presumed educational theory that was not on our list, they consulted other coders to see if this was an additional educational theory eligible for coding. After making these changes to the framework, a total of 12 articles were selected and each coded by two coders (Akintewe et al. 2019; Clavijo and Pochiraju 2019; Greetham and Ippolito 2018; Jensen et al. 2018; Lara-Prieto et al. 2020; Mabley et al. 2020; Nolen and Koretsky 2018; Qamara et al. 2016; Tomkinson and Hutt 2012; Volpentesta et al. 2012; Heylen et al. 2010; Santoso et al. 2018). Using Cohen (Cohen 1960), the Inter-Rater Reliability (IRR) was calculated (see Table 1). On all scales, IRR was high and can be interpreted as 'substantial' to 'almost perfect'. Any remaining disagreements between coders were discussed until a consensus was reached.

Table 1. Scales that are used in the framework. Theory here refers to educational theory. The Interrater Reliability (irr) is reported for the 12 papers coded.

Scale	irr	0	1	2	3	4
abstract	1.00	not mentioned	mentioned			
background	.82	not mentioned	mentioned without reference	mentioned with reference, but no additional information	mentioned with reference **+** additional definition, explanation, or example	
intervention design	.79	not mentioned	mentioned, but not explicitly connected with the design	explicitly connected with the design of intervention		
intervention analysis	.81	not mentioned	mentioned, but not explicitly connected with results of the intervention	explicitly connected with results of the intervention	practical implications with relation to the theory are derived from the results	advanced through findings

3.3 Framework and workflow

Framework. The designed framework is shown in Fig. 1. The left column lists commonly encountered educational theories. Additional educational theories found are added under 'additional educational theories'. Per paper, a coder assesses the embedding of all found theories on four aspects: (1) abstract, (2) background, (3) design of the intervention, and (4) analysis of the intervention. The developed scales (Table 1) have numerical codes that represent the extent to which an educational theory was integrated into a paper.

Workflow. The workflow of the framework consists of two phases and is visualised in Fig. 2. The first phase shows the identification of all educational theories mentioned in a paper. The second phase focuses on the extent to which educational theories are embedded in a paper.

	Lara-Prieto				Greetham				Heylen			
Learning Theories	Abstract	Rel. work	Design	Analysis	Abstract	Rel. work	Design	Analysis	Abstract	Rel. work	Design	Analysis
Cognitivism												
(Socio)-Constructivism					0	3	0	0				
Situated learning/ situated perspective												
Socio-cultural theory												
Socio-cognitive perspective												
Challenge-based learning	0	1	0	0								
Competition-based learning												
Game-based learning												
Group-based learning												
Inquiry-based learning												
Problem-based learning					0	2	0	0				
Project-based learning	0	0	1	0					1	1	0	0
Team-based learning					1	3	2	3				
Active learning	1	1	0	0	0	3	0	0				
Computer Supported Collaborative Learning												
Collaborative learning	1	1	0	0								
Cooperative learning												
Experiential learning												
Self-regulated learning												
Service learning												
Constructive alignment												
Flipped classroom					0	1	0	0				
Additional Learning Theories												
Competency based learning	0	0	0	1								

Fig. 1. Overview of the framework

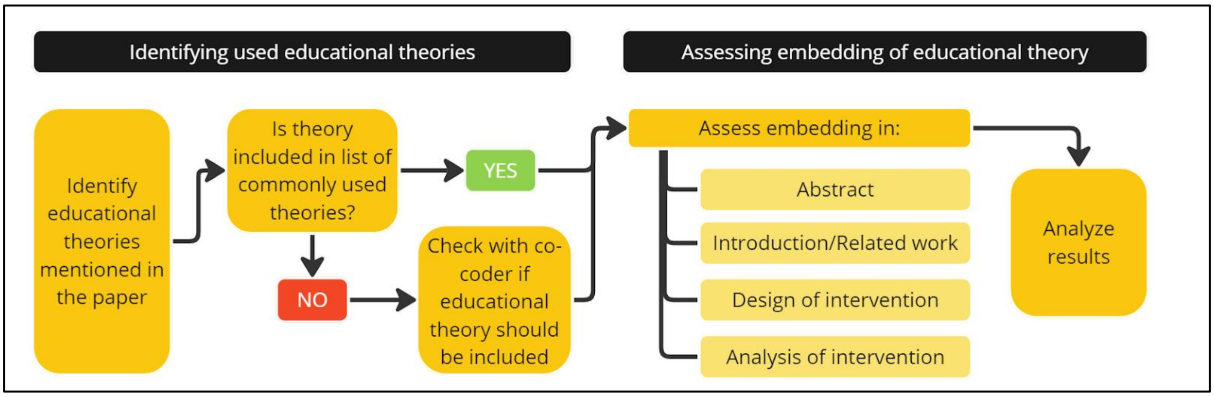

Fig. 2. Workflow: identifying & assessing embedding of educational theory

4 RESULTS

In this section, we demonstrate the relevance of the developed framework by presenting the results from the last iteration of our small subset of 12 papers, thus illustrating what type of results can be retrieved from the developed framework.

4.1 Which theories are used and to what extent?

In our sample, each article mentioned at least one educational theory. We encountered a total of 45 mentions of 22 unique educational theories. An overview of all educational theories mentioned is listed in Appendix 1. Most popular theories concern a specific pedagogical approach (e.g., project-based learning, collaborative learning), whereas philosophies on learning (theories on how people learn, such as constructivism) occur less frequently. Using the scales in our framework allowed us to make observations on the extent to which theories were integrated in different parts of a study.

Background. Theories mentioned in the introduction or related work were not always well explained. Of the 12 selected papers, 4 do not introduce any mentioned educational theories in the introduction or related work, or, if they did, no reference connected to the theory was provided (Jensen et al. 2018; Lara-Prieto et al. 2020; Nolen and Koretsky 2018; Heylen et al. 2010). Only half of the papers introduced educational theories in the background with additional definitions, explanations, examples, or references. In total, only 14 out of 45 mentions of theory are introduced with a reference and a definition, explanation, or example; 11 theories are mentioned with a reference and 10 without a reference. 10 Theories were mentioned without any introduction.

Design of intervention. Only 6 out of 12 articles ground the design of their learning activity explicitly in educational theories (Akintewe et al. 2019; Clavijo and Pochiraju 2019; Greetham and Ippolito 2018; Mabley et al. 2020; Volpentesta et al. 2012; Santoso et al. 2018). In total, eight unique theories are used to ground design choices, and four unique theories are mentioned when describing the intervention, but without making the connection with its design. Just 14 out of 45 mentions of theory (11 unique) are listed in the intervention design, of which project-based learning is the most popular (4). Furthermore, 5 out of 12 articles describe an intervention without referring to educational theory, even though their combined papers mention 31 theories (19 unique) (Jensen et al. 2018; Tomkinson and Hutt 2012; Qamara et al. 2016; Nolen and Koretsky 2018; Heylen et al. 2010).

Analysis of intervention. Two articles do not mention any educational theory during the analysis of their intervention (Qamara et al. 2016; Heylen et al. 2010). In addition, four mention theories, but never connect them to their results (Jensen et al. 2018; Clavijo and Pochiraju 2019; Lara-Prieto et al. 2020; Nolen and Koretsky 2018). Four articles make a connection between educational theory and their results (in total 8 unique theories), but no implications are derived (Clavijo and Pochiraju 2019; Jensen et al. 2018; Nolen and Koretsky 2018; Santoso et al. 2018). Finally, two papers provide practical implications related to three unique educational theories (Greetham and Ippolito 2018; Mabley et al. 2020). None of the papers advance existing theories by adding new knowledge on a theoretical level.

4.2 Observations on the use of theories in a paper

With the help of our framework, we can make several observations on the use of theories in a paper. First, theories are not uniformly nor consistently used in papers in their descriptions of background, intervention, and analysis (Appendix 1). Some theories, such as jigsaw (Akintewe et al. 2019), are mentioned consistently throughout the paper. Other theories, such as collaborative learning, project-based learning, and constructivism are primarily covered in the introduction and background.

Furthermore, occasionally, theories are mentioned as a keyword or in the abstract, but do not appear in the actual paper (Clavijo and Pochiraju 2019; Qamara et al. 2016). Additionally, 13 theories are only covered in the background of a paper, the most common being active learning (2), collaborative learning (3), constructivism (2), and project-based learning (3). Finally, 10 theories are used in the design or analysis of an intervention, but are not introduced in the background of the paper (Lara-Prieto et al. 2020; Nolen and Koretsky 2018; Tomkinson and Hutt 2012; Santoso et al. 2018).

5 DISCUSSION

In agreement with earlier studies (Malmi et al. 2018; Borrego et al. 2013), we found that educational theories are frequently mentioned. However, analysis of our sample revealed that half of the included studies do not ground the design of their intervention explicitly in educational theory. Even fewer articles list generalizable implications in relation to the educational theory during their intervention analysis. This implies that, although educational theories are mentioned, studies rarely deeply engage with these theories. The lack of connection with educational theories during the intervention analysis can be due to the type of educational theories used. Theories on pedagogical approaches were found to be the most popular. These theories, however, may be more suitable to inform the design of a learning activity than to analyze the learning triggered by that learning activity. It may be preferable to draw on theories that focus on describing and explaining behavior. Within EER, there are scientific works that can guide researchers in using this type of theories, such as (Johri et al. 2011).

Furthermore, our finding that some theories were only mentioned in the background, with or without reference, or in the abstract may indicate that these theories, such as active learning, collaborative learning, etcetera, are considered ‘well established’ and need no further explanation. In addition, it may be that these theories are only mentioned to embed the presented work in popular theorems. Sadly, by not adding references authors are denying readers necessary information.

Finally, the fact that a substantial number of theories are used in the design or analysis of an intervention while never being (properly) introduced in the background of the paper, may suggest these theories do not need further explanation and are well embedded in EER. Conversely, it may also be a sign of unawareness of the theories of the authors themselves. We have seen that in some cases, theories were only mentioned and not connected to design choices or to the results. This may suggest that our findings are in favor of the latter explanation.

The framework does have limitations. First, it is designed for identifying educational theories, which means that studies that have embedded theories from another field, even to the extent of having a solid foundation and integration in design and analysis, were not captured using this framework. Also, the framework has only been tested on a small body of literature relating to one educational topic. It needs to be more rigorously applied to more literature on more topics. Finally, our distinction between 'philosophies of learning' and 'pedagogical approaches' is preliminary, and a full classification scheme for 'type of learning theory' needs to be developed in the future.

Overall, our initial analysis of a small body of literature already highlights the advantages of using the framework to strengthen the theoretical embedding of the body of literature. The framework can be used as a diagnostic tool to analyze and quantify which theories are used in EER literature (and related fields) and how. Moreover, the framework can guide ways to find consensus in a field.

6 FUTURE WORK

Further research will extend the current analysis to the full body of literature on collaborative engineering design activities to verify trends observed in our current subset of literature. Moreover, as this framework can be generalized to any other body of literature that describes educational interventions, we aim to apply the framework to other topics relevant to the EER community, including programming education and AI education. Additionally, using the framework on a large body of literature would allow for pattern analysis regarding often recurring "paths" of an educational theory per paper. This in turn would support further evaluation of how well individual papers are embedded in educational theories, as well as how well individual theories are embedded in EER and related disciplines.

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APPENDIX 1

Table A1: All theories mentioned in the 12 coded papers, with the total number of papers mentioning them (N), the respective papers, and the number of papers that mention them per scale. The theories are categorized by embedding.

PA=Pedagodical Approach, PL=Philosohy of Learning. This classification is ***preliminary.***

Theory	Type	N	Papers	Abstract	Background	Intervention	Analysis
Project-based learning	PA	8	(Clavijo and Pochiraju 2019; Jensen et al. 2018; Lara-Prieto et al. 2020; Mabley et al. 2020; Qamara et al. 2016; Volpentesta et al. 2012; Heylen et al. 2010; Santoso et al. 2018)	4	7	4	3
Active learning	mixed	5	(Greetham and Ippolito 2018; Lara-Prieto et al. 2020; Mabley et al. 2020; Qamara et al. 2016; Santoso et al. 2018)	2	3	1	1
Collaborative learning	PA	5	(Clavijo and Pochiraju 2019; Lara-Prieto et al. 2020; Qamara et al. 2016; Volpentesta et al. 2012; Santoso et al. 2018)	4	4	1	1
Problem-based learning	PA	3	(Greetham and Ippolito 2018; Mabley et al. 2020; Tomkinson and Hutt 2012)	2	3	1	2
Flipped classroom	PA	2	(Clavijo and Pochiraju 2019; Greetham and Ippolito 2018)	1	1	1	1
Team-based learning	PA	2	(Greetham and Ippolito 2018; Qamara et al. 2016)	2	2	1	1
Jigsaw	PA	1	(Akintewe et al. 2019)	1	1	1	1
Situated learning	PL	1	(Mabley et al. 2020)	-	1	1	1
Constructivism	PL	3	(Greetham and Ippolito 2018; Mabley et al. 2020; Volpentesta et al. 2012)	-	3	1	-
Cooperative learning	PA	2	(Akintewe et al. 2019; Volpentesta et al. 2012)	1	2	1	-
Experiential learning	PA	2	(Volpentesta et al. 2012; Tomkinson and Hutt 2012)	-	1	-	1
Computer supported collaborative learning	PA	1	(Jensen et al. 2018)	-	1	-	1
Group-based learning	PA	1	(Tomkinson and Hutt 2012)	-	1	-	1
Self-regulated learning	PL	1	(Santoso et al. 2018)	-	1	-	1

Theory	Type	N	Papers	Abstract	Background	Intervention	Analysis
Case-based group discussion	PA	1	(Greetham and Ippolito 2018)	-	1	-	-
Challenge-based learning	PA	1	(Lara-Prieto et al. 2020)	-	1	-	-
Constructive alignment	other	1	(Mabley et al. 2020)	-	1	-	-
Social-cultural theory	PL	1	(Mabley et al. 2020)	-	1	-	-
Service learning	PA	1	(Akintewe et al. 2019)	1	-	1	-
Bridging epistemologies	other	1	(Nolen and Koretsky 2018)	-	-	-	1
Competency-based education	PA	1	(Lara-Prieto et al. 2020)	-	-	-	1
Knowledge building theory	PL	1	(Nolen and Koretsky 2018)	-	-	-	1